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Trawl Comparisons and Fishing Power Corrections for the *F/V Northwest Explorer, R/V TINRO,* and *R/V Kaiyo Maru* During the 2002 BASIS Survey.

by

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ABSTRACT

This document summarizes research trawl comparisons and fishing power corrections for the *F/V Northwest Explorer*, *R/V TINRO*, and *R/V Kaiyo maru* during the 2002 BASIS (Bering-Aleutian Salmon International Survey) survey. The BASIS research vessels completed joint trawling at twelve stations in the Bering Sea between September 12 and September 18, 2002. The *Kaiyo maru* (Japan) and the *Northwest Explorer* (United States) completed joint trawling at five stations, the *Northwest Explorer* and the *TINRO* (Russia) completed joint trawling at six stations, and all three vessels completed joint trawling at one station. Four of the six stations sampled by the *Northwest Explorer* and the *TINRO* were part of a diel study, where the same station was sampled four times (every six hours for 24 hours). Trawls differed in their headrope length and number of wingtips; trawls were configured with different bridle lengths, warp lengths, door sizes, and footrope weights; and vessels differed in their size and horsepower. These differences resulted in differences in sampling depth (vertical opening of the trawl), trawl width, warp length, and trawling speed. Catch rates were standardized for the average area swept during each trawl haul by all three vessels (0.37 km^2 of seawater). Immature chum salmon (*Oncorhynchus keta*), sockeye salmon (*O. nerka*), chinook salmon (*O. tshawytscha*), and juvenile Atka mackerel (*Pleurogrammus monopterygius*) were the primary species and life-history stages caught during the trawl comparisons. Generalized linear models were used to fit fishing power models to catch and catch rates with a robust maximum likelihood approach. The *Kaiyo maru* had the largest fishing power for both catch and catch rates, followed by the *TINRO* and the *Northwest Explorer*. The largest difference in fishing power consistently occurred between the *Kaiyo maru* and the *Northwest Explorer*. The *TINRO* and the *Northwest Explorer* were most similar in their fishing power for salmon, whereas the *Kaiyo maru* and *TINRO* were most similar in their fishing power for Atka mackerel. Fishing power corrections were larger for catch than catch per unit of effort (CPUE) due to different effort levels by each vessel. Fishing power coefficients for CPUE of all species were significant at the $p<0.10$ level; however, only Atka mackerel was significant at the $p<0.05$ level. Fishing power coefficients for catch of all species except sockeye salmon were significant at the $p<0.10$ level; Atka mackerel and chinook salmon were significant at the $p<0.05$ level. Although large differences exist in the sampling characteristics of pelagic trawls used by BASIS vessels (particularly with respect to sampling depth, or vertical trawl opening), fishing power models provide reasonable corrections for differences in fishing power. However, caution should be used when applying these fishing power correction terms because the small number of stations used to compute fishing power estimates limits our ability to ensure that correction terms are applicable to other areas and times.

INTRODUCTION

The Bering-Aleutian Salmon International Survey (BASIS) is a cooperative research program by member nations of the North Pacific Anadromous Fisheries Commission (NPAFC). The BASIS program was created to address critical information gaps for the marine phase of Pacific salmon (*Oncorhynchus* spp.) through seasonal pelagic trawl surveys on the distribution, abundance, and stock origins of salmon in the Bering Sea (NPAFC, 2001). A key factor in the ability of BASIS to accomplish this objective is ensuring that catches are comparable between different BASIS research vessels. Trawl comparison were completed by the R/V *Kaiyo maru*, F/V *Northwest Explorer*, and R/V *TINRO* in the central Bering Sea between September 14 and 17, during the 2002 BASIS survey (Figure 1). This report summarizes the results of the trawl comparison study, which is the first comparison of pelagic trawls used by BASIS research vessels, and the first estimates of fishing power differences between these vessels.

METHODS

Catch Rate

Catch rates (catch per unit of effort, or CPUE) were estimated for each vessel at each station sampled during the gear comparisons. The standard unit of effort used was 0.37 km^2 of seawater swept by the trawl, which was the average area swept by all vessels during the trawl comparisons. Effort was estimated by multiplying the horizontal spread of the trawl by the distance trawled. All vessels did not have the capability of measuring distance traveled through water therefore distance trawled over ground was used. Estimates of distance trawled were computed by multiplying the average vessel speed by trawl duration (one hour). Estimates of distance trawled we also computed from the start (lat_1, lon_1) and end (lat_2, lon_2) trawl positions by converting latitude and longitude positions from degrees to radians and using spherical coordinates to determine the distance (arc-length) between them using:

$$D = ArcCos[Sin(lat_1)Sin(lat_2) + Cos(lat_1)Cos(lat_2)Cos(lon_1 - lon_2)] * R,$$

where R equals the mean radius of the earth (6371 km) and D equals the distance trawled.

Fishing Power Models

Fishing power is a measure of the efficiency at which a particular vessel-gear combination captures fish. The measure presents a standardization problem when multiple vessel-gear combinations are used during a survey or when a change in a standard vessel or gear is made over time. Due to the difficulty in defining absolute fishing power, fishing power is often defined by reference to a standard vessel-gear combination through comparative trawling experiments where vessels fish at the same time and place.

Fishing power models were constructed by assuming each vessel's expected catch rate (CPUE) is proportional to abundance by a catchability term, q, so that:

$$E(CPUE) = qN.$$

If vessels fishing side-by-side are assumed to encounter the same abundance of fish, then catch rates can be expressed as:

$$E(CPUE_{ij}) = q_i N_j, \quad (1)$$

where $CPUE_{ij}$ is the catch rate of the i^{th} vessel at the j^{th} station. Fishing power models were derived from Equation 1 as:

$$E(CPUE_{ij}) = q_r N_s \left(\frac{q_i}{q_r} \right) \left(\frac{N_j}{N_s} \right) = qa_i b_j, \qquad (2)$$

where r and s are the reference vessel and station, respectively.

Fishing power models were fit using the generalized linear model format in the Splus[1] statistical language (McCullagh and Nelder, 1989; Chambers and Hastie, 1992). Generalized linear models (GLMs) provide a way of estimating a function of the mean response as a linear combination of a set of predictors, $\boldsymbol{X}=(X_1, \ldots)$, as in the following:

$$g(E(Y \mid X)) = g(u) = y_0 + \sum_i y_i X_i,$$

where $g(u)$ is called a link function. The GLM parameters are estimated by maximizing the likelihood function with iteratively reweighted least squares (McCullagh and Nelder, 1989; Chambers and Hastie, 1992). A robust maximum likelihood estimator was used, which minimizes a tapered residual deviance term, D_w, instead of the typical squared residual deviance term D_i. The robust residual deviance term is computed as:

$$D_w = \sum_{i=1}^{n} f w_k \left(\frac{D_i}{f} \right),$$

where ϕ is a dispersion parameter used to standardize residuals, and w_k dampens the residual influence for standardized residuals larger than k^2 (Huber, 1964). The w_k term is express as:

$$w_k(t) = \begin{Bmatrix} t & \text{for } t \le k^2 \\ 2kt^{1/2} - k^2 & \text{for } t > k^2 \end{Bmatrix}.$$

Robust estimation involves calculating estimators that are relatively insensitive to the tails of a data distribution but conform to normal theory approximation at the center of the data distribution. The recommended value for the shape parameter, k=1.345, was used, giving D_w an efficiency of 95% (efficiency in obtaining minimum variance solutions) while maintaining a high resistance to data at the tails of the distribution.

Error structure was assumed to be log-normal for species where zero catches were not encountered (chum salmon, total salmon, and Atka mackerel), and Poisson with a log link

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, or by NOAA.

function for species where zero catches were encountered (sockeye and chinook salmon). Log-normal error models were fit to log-transformed catch rates from Equation 2 with Gaussian error and an identity link, expressed as:

$$g\left(E\left(\log\left(CPUE\right)\mid \mathrm{X}\right)\right)=E\left(\log\left(CPUE\right)\mid \mathrm{X}\right)=\log(q)+\sum_{i=1}^{2}a_i X_i+\sum_{j=1}^{11}b_j X_j, \quad (3)$$

where $\boldsymbol{X}=(X_{1}, \ldots, X_{13})$ are dummy variables used to estimate the a_i and d_j coefficients by assigning each variable values of one or zero as appropriate. Three vessels and 12 stations were included in the trawl comparisons, requiring 2 dummy variables for vessel coefficients and 11 dummy variables for station coefficients. Poisson models of the same form on the right-hand side of Equation 3 were fit to untransformed catch rates with a Poisson error and a log link function,

$$g\left(E(CPUE)\mid X\right)=\log(E(CPUE)\mid X).$$

The Poisson assumption is reasonable for small catches, including zeros. Transformed coefficients, $\hat{a}_i$ = exp(a_i), can be used as fishing power correction terms to scale catch rates of a reference vessel to those expected for vessel i:

$$CPUE_{rj} * \boldsymbol{a}_i = q_r N_j\left(\frac{q_i}{q_r}\right)=q_i N_j = CPUE_{ij}.$$

Standard errors of the fishing power correction terms were approximated with the delta method (Seber, 1982) by:

$$se\left(a_i\right)=e^{a_i}se(a_i).$$

Significance of the fishing power term was tested using Fisher's distribution as:

$$\Pr(F)=1-F\left(\frac{D_a/df_a}{D/df}, df_a, df\right),$$

where D is the residual deviance of the full model and df is the degrees of freedom for D ; D_a is the reduction in residual deviance by including the fishing power term, and df_a is the degrees of freedom (df_a=2) for D_a. This test is described for GLM's by McCullagh and Neldor (1989).

Trawl Configuration

United States

All trawling was conducted by the *F/V Northwest Explorer* (B&N Fisheries Company, Seattle, WA) with a Cantrawl model 400/580 (made by Cantrawl Pacific Ltd., Richmond, B.C.) midwater rope trawl (Figure 2) towed with the headrope at the surface. The *Northwest Explorer* is a 50.3-m chartered factory trawler with a main engine horsepower of 1800 hp (900 hp×2), a cruising speed of 9.5 knots, and a warp diameter of 29 mm (die-compressed from 32 mm). The Cantrawl 400/580 trawl has hexagonal mesh in the wings and body, is 198 m in length, has a headrope length of 120 m, and has a 12-mm mesh liner in the codend. The trawl was configured with three 60-m (19-mm diameter) bridle legs connecting the trawl to the trawl doors (Figure 3). Steel alloy 5-m^2 trawl doors with fixed bails from Noreastern Trawl (NETS) were used. An additional 91-kg steel plate was added to the shoe of each door to increase stability. Total weight of each door was approximately 613 kg. Three polyform floats (one 80-cm and two 60-cm) were attached to the headrope on both wingtips, and six 31-cm center-hole trawl floats were attached to the net sonar kite at the headrope to help keep the headrope at the surface; a 120-kg chain was used to allocate the weight along the footrope. Main warp was set at 350–400 m, and target towing speeds were 4.5–5.0 knots.

Russia

All trawling was conducted aboard the *R/V TINRO* (TINRO-Centre, Vladivostok) using a hexagonal mesh midwater rope trawl, model PT 80/396 (Figure 4, Tables 1 and 2) towed with the headrope at the surface. Trawl and vessel characteristics are described in Temnykh et al. (2002). The *TINRO* is a 62.22×13.81 m stern trawler of 2,508 t with a cruising speed of 12.96 knots, a main engine horsepower of 2364 (1182 hp×2), and a warp diameter of 32 mm. The trawl is 130 m long with hexagonal mesh in the wings and body, a headrope length of 80 m, and a 10-mm mesh liner in the codend. Trawl bridles consisted of two 100-m main trawl bridles connected to a single point behind each door, and four 50-m split bridles connected to four points on each side of the trawl (Figure 5). Bridles were attached to two conical V-shaped trawl doors (area 6 m^2, weight 1300 kg). A hydrodynamic plate (area 6 m^2, height 0.6 m, length 10 m) and floats were used on the headrope to keep it at the surface. Two 400-kg weights were attached to the footrope bridles directly in front of the footrope, and a 120-kg chain was used to allocate the weight along the footrope and to increase the vertical spread of the trawl. Vertical spread of the trawl ranges between 32-42 m and horizontal spread ranges from 30-34 m depending on towing speed and warp length of the vessel. Vertical spread during towing time is constantly measured by a Wesmar TCS 704E net sounder.

Japan

All trawling was conducted aboard the *R/V Kaiyo maru* (Fisheries Agency of Japan, Tokyo) with a NICHIMO model NST-60-K1 surface rope trawl (manufactured by NICHIMO CO. LTD., Japan) towed with the headrope at the surface. The *Kaiyo maru* is a 93.01 m stern trawler of 2,630 t with a main engine horsepower of 7000 (3500 hp×2) and a warp diameter of 32 mm. The NICHIMO NST-60-K1 rope trawl has a total length of 202.2 m, a headrope length of 63 m, a hexagonal mouth opening, and a 13-mm liner in the codend, with a typical vertical and horizontal spread of 60×60 m (Figure 6). Trawl bridles consisted of two 20-m main trawl bridles behind each door, and six 98-m split bridles connected to three points on each side of the trawl (Figure 7). Main bridles were attached to two steel trawl doors (area 9 m^2, weight 1450 kg underwater). Fifty 208B floats were attached to the headrope to keep it at the surface, and eight 147.4-kg weights were attached to the front of the trawl to sink the footrope; a 120-kg chain was attached to the footrope to distribute weight along the footrope. The trawl is towed at the surface at 5 knots with 250 m of warp.

RESULTS AND DISCUSSION

The BASIS research vessels completed joint trawling at twelve stations in the Bering Sea between September 12 and September 18, 2002 (Table 3). The *R/V Kaiyo maru* and the *F/V Northwest Explorer* completed joint trawling at five stations, the *Northwest Explorer* and the *R/V TINRO* completed joint trawling at six stations, and all three vessels completed joint trawling at one station. Four of the six stations sampled by the *Northwest Explorer* and the *TINRO* were part of a diel survey where the same station was sampled every six hours for a period of 24 hours.

Differences were present in the trawling characteristics of the vessels. Trawls differed in their headrope length and number of wingtips; trawls were configured with different bridle lengths, warp lengths, door sizes, and footrope weights; and vessels differed in their size and horsepower. These differences resulted in differences in the vertical trawl opening, trawl width, warp length, and trawling speed. Significant differences were present in the average vertical trawl openings: 17 m for the *Northwest Explorer*, 36 m for the *TINRO*, and 50 m for the *Kaiyo maru* (Table 3). Differences in the vertical trawl opening can have an effect on catch rate if the vertical distribution of fish is non-uniform over the depths sampled or if the vertical distribution changes with time or area. More similarity was present in trawling widths (horizontal spread). Average trawling widths were: 45 m for the *Northwest Explorer*, 33 m for the *TINRO*, and 50 m for the *Kaiyo maru*. Average warp lengths were: 366 m for the *Northwest Explorer*, 277 m for the *TINRO*, and 250 for the *Kaiyo maru*. Warp length (the distance between the trawl doors and the vessel) could affect catch rates if vessel avoidance is a significant factor in catch rate. Average trawling speeds were: 4.11 knots for the *Northwest Explorer*, 4.79 knots for the *TINRO*, and 5.85 knots for the *Kaiyo maru*. Trawling speed could affect catch rates if net avoidance is a significant factor in catch rate.

Immature chum salmon (*Oncorhynchus keta*), sockeye salmon (*O. nerka*), chinook salmon (*O. tshawytscha*), and juvenile Atka mackerel (*Pleurogrammus monopterygius*) were the primary species and life-history stages caught during the trawl comparisons. About 95% of the salmon caught during the gear comparison were chum salmon; no juvenile salmon were caught (Table 4). The number of stations sampled during the diel sampling was inadequate to define a diel pattern in salmon or Atka mackerel catches. However, there was not an apparent increase in salmon catch in the surface trawls during the night sets made by the *Northwest Explorer* and the *TINRO* (stations 9 and 12) (Table 4). An increase would be expected if there was a significant diel vertical migration and salmon were deeper than the sampling depth of the trawls during the day. Although not detailed in this report, there was an obvious diel pattern present in trawl catches of squid (*Gonotopsis borealis* and *Onychoteuthis borealijaponica*, but not *Gonatus kamschaticus*), and myctophid species (*Diaphus theta*, *Leuroglossus schmidti*, *Stenobrachius leucopsarus*), with the largest catches occurring during the night.

Atka mackerel catch rates were significantly higher than catch rates for salmon by all vessels. The *Kaiyo maru* had the greatest difference in catch rates between Atka mackerel and salmon, and the *Northwest Explorer* had the least difference. Sockeye salmon were captured at the lowest rate during paired trawls by the *Kaiyo maru* and the *Northwest Explorer*; chinook salmon were captured at the lowest rate during paired trawls by the *TINRO* and the *Northwest Explorer*. Average catch rates by the *Kaiyo maru* and the *TINRO* were consistently higher than catch rates by the *Northwest Explorer* during the paired trawling experiments. Although the *TINRO* had the highest catch rates for all species except chinook salmon, this does not mean the *TINRO* had the highest fishing power for these species. Catch rates by the *Northwest Explorer* for all species except chinook salmon were approximately twice as high during the paired trawling with the *TINRO* than with the *Kaiyo maru*; therefore, catch rates by the *TINRO* would need to be twice that of the *Kaiyo maru* to have a similar fishing power for these species. The sampling design used during the trawl comparisons (vessels not fishing together at all locations) requires the use of fishing power models that correct for changes in abundance by location to accurately estimate fishing power differences between vessels.

Fishing power correction terms were estimated for catch and catch rates of salmon and Atka mackerel (Tables 7 and 8; Figures 8 and 9). Fishing power corrections were larger for catch than for CPUE due to different effort levels by each vessel. The *Kaiyo maru* had the largest fishing power for both catch and catch rates, followed by the *TINRO* and the *Northwest Explorer*. The largest difference in fishing power consistently occurred between the *Kaiyo maru* and the *Northwest Explorer*. The *TINRO* and the *Northwest Explorer* were most similar in their salmon fishing power, whereas the *Kaiyo maru* and *TINRO* were most similar in their fishing power for Atka mackerel.

Robust fits to log-normal models (chum salmon, total salmon, and Atka mackerel) were identical to maximum likelihood (MLE) estimates with respect to the estimated coefficients, standard errors, and p-values. Robust fits to log-Poisson models (sockeye and chinook salmon) differed from the MLE estimates, indicating a lack of robustness in the log-Poisson models. This lack of robustness is most likely due to an increased sensitivity to the equal abundance assumption when catch levels are low. Fishing power models used in this analysis require the assumption that vessels fishing side-by-side encounter the same abundance of fish.

The p-values from the Fisher's test of significance are shown in Table 9. All fishing power coefficients were significant at the $p<0.10$ level for CPUE; however, only the Atka mackerel coefficient was significant at the $p<0.05$ level. All fishing power coefficients except the sockeye salmon coefficient were significant at the $p<0.10$ level for catch; however, only the Atka mackerel and chinook salmon coefficients were significant at the $p<0.05$ level.

Although large differences exist in the sampling characteristics of pelagic trawls used by BASIS vessels (particularly with respect to sampling depth, or vertical trawl opening), fishing power models provide reasonable corrections for differences in fishing power. However, caution should be used when applying these fishing power correction terms. The small number of stations used to compute fishing power estimates limits our ability to ensure that correction terms can be applicable to other areas and times. Correction terms may not be applicable to abundance levels that are significantly different than those observed during the calibration experiment. Due to the different vertical opening of the trawls used by the respective BASIS vessels, vertical distribution patterns in salmon and Atka mackerel abundance may alter fishing power correction terms. Other habitats or life-history stages of salmon and Atka mackerel that result in different vertical distributions will alter the correction terms required to standardize catch rates.

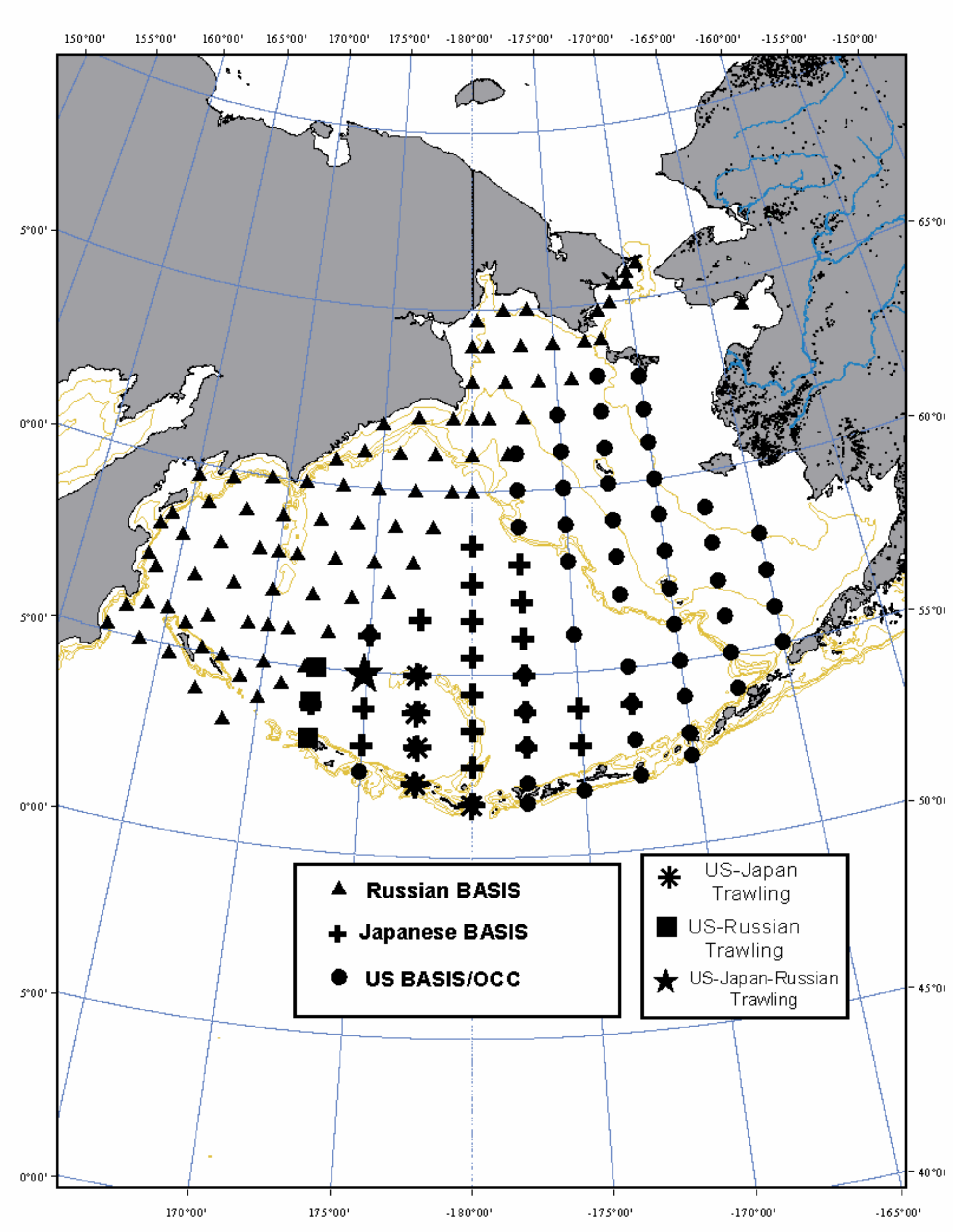


Figure 1. Sampling locations by the BASIS research vessels *Northwest Explorer* (United States), *TINRO* (Russia), and the *Kaiyo maru* (Japan) during the BASIS survey in the Bering Sea—September-October, 2002. Locations of the trawl comparisons are shown.

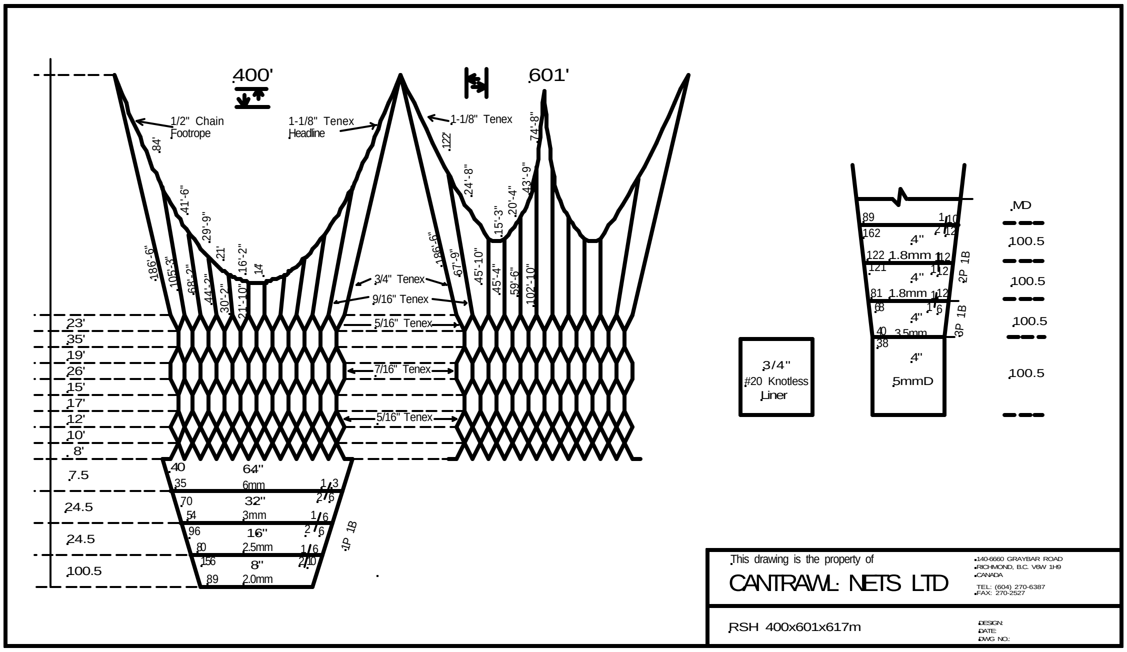


Figure 2. Top and side drawings of the rope trawl (Cantrawl 400/580) used aboard the *Northwest Explorer* during the 2002 BASIS survey.

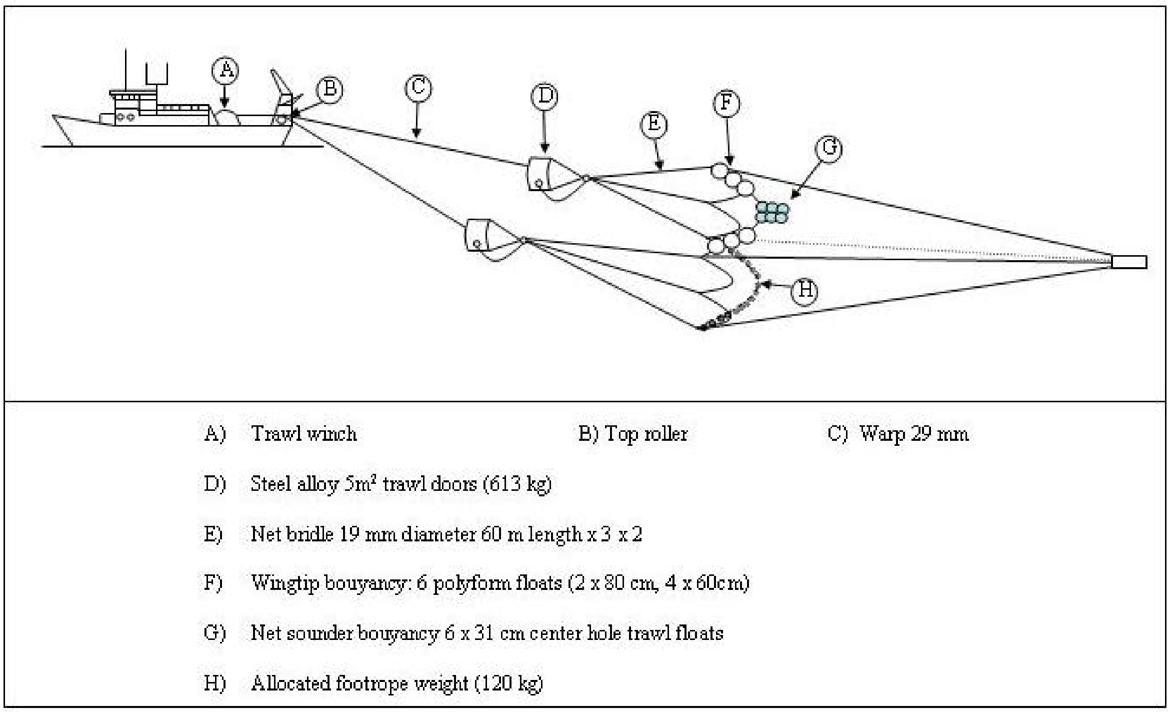


Figure 3. Rope trawl configuration used aboard the *Northwest Explorer* during the 2002 BASIS survey.

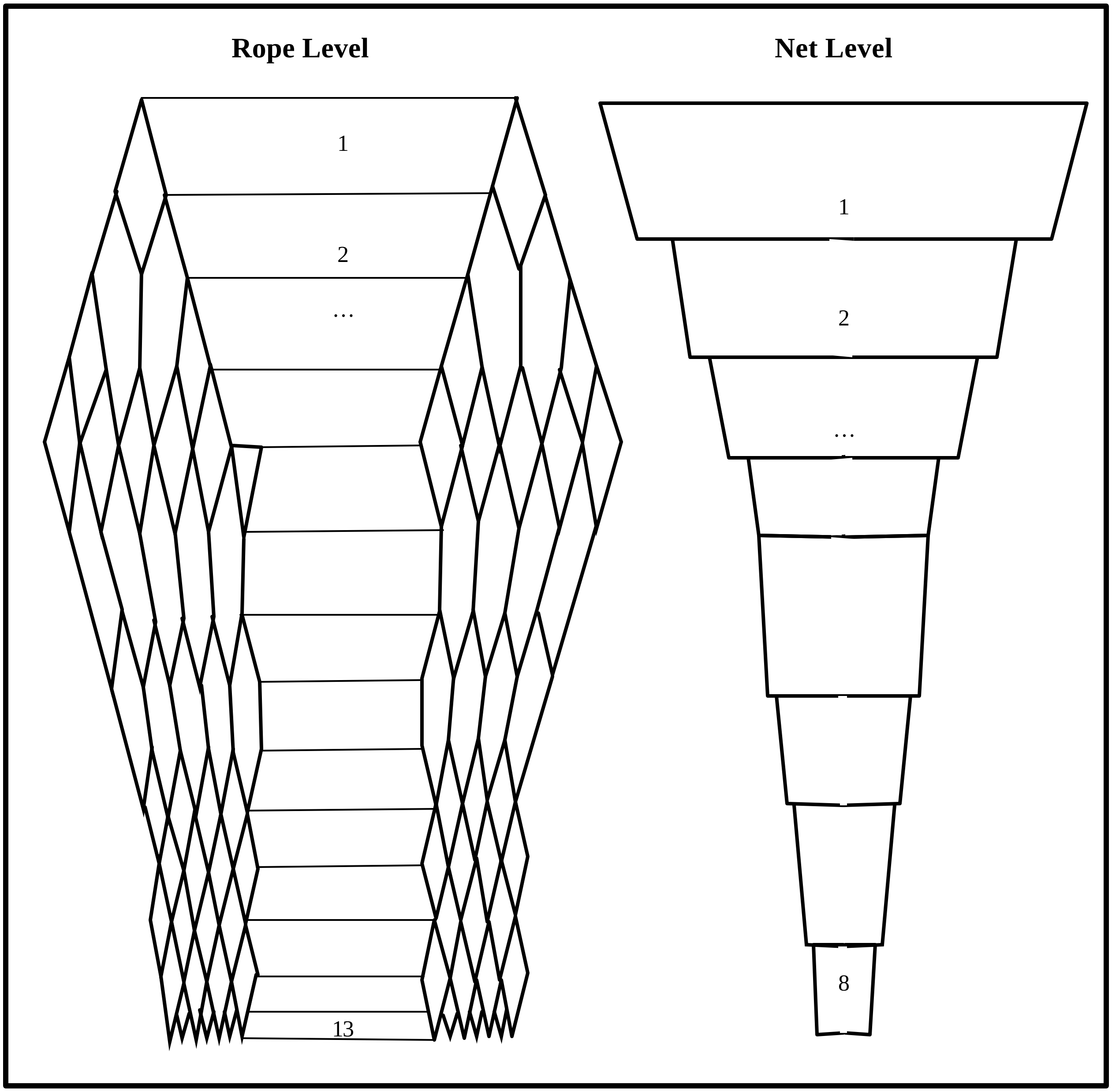
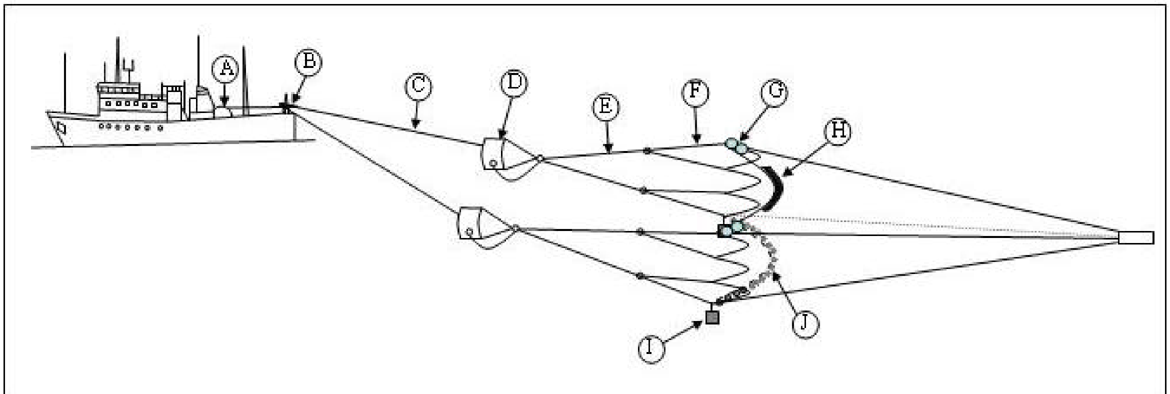


Figure 4. Model PT 80/396 rope trawl used aboard the *TINRO* during the 2002 BASIS survey.



A) Trawl winch

B) Top roller

C) Warp 32 mm

D) Steel alloy 6 m^2 trawl doors (1300 kg)

E) Main net bridles 19 cm diameter 100 m length (2 x 2)

F) Split net bridles 19 cm diameter 50 m length (2 x 4)

G) Headrope floats

H) Elevating system (hydrodynamic plate: 0.6 m x 10 m)

I) Main footrope weight 400 kg (2)

J) Allocated footrope weight (120 kg chain)

Figure 5. Rope trawl configuration used aboard the *TINRO* during the 2002 BASIS survey.

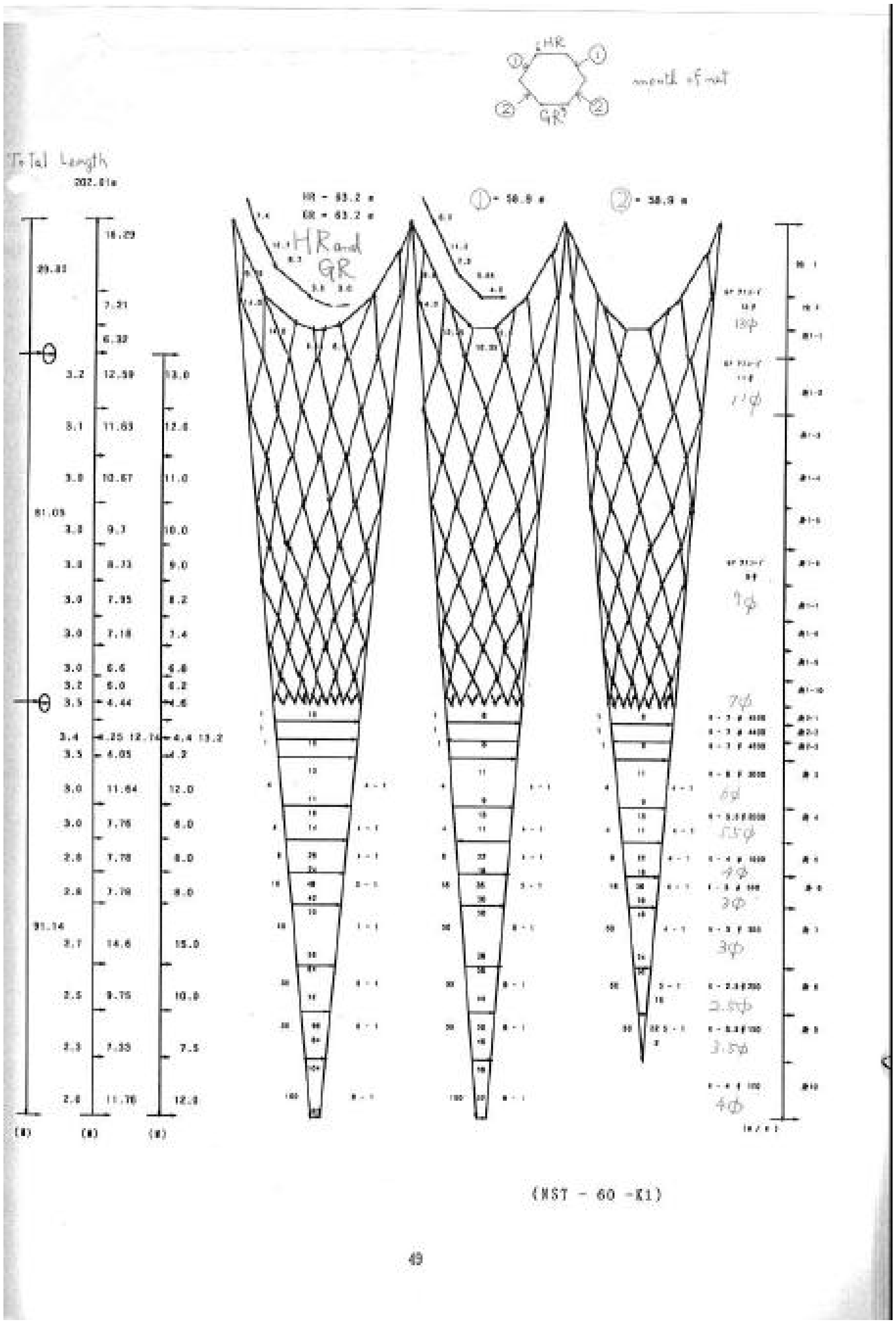
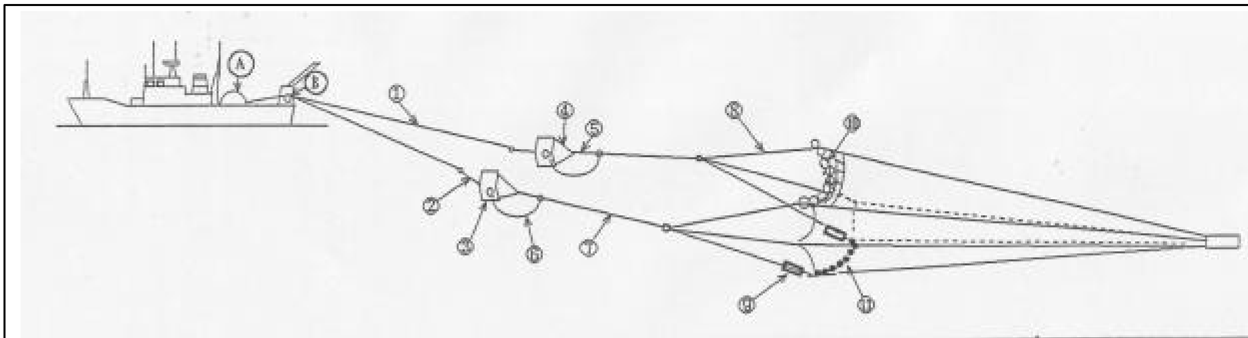


Figure 6. Top and side drawings of the rope trawl (NICHIMO NST-60-K1) used aboard the *Kaiyo maru* during the 2002 BASIS survey.



A) Trawl winch

B) Top roller

1) Warp 32 mm

2) Towing chain 42×67×168 mm × 17 R(L=2856mm)×2

3) Steel twin trawl door 2.4×3.75 m (9 m^2) 1450 kg under water

4) Back straps 26 mm × 13 m × 2 × 2

5) Back straps leg 26 mm × 2 m × 2

6) Idler 30 mm 21.4 m × 2

7) Sweep line 32 mm × 20 m × 2

8) Net bridle 22 mm × (98 m + 6 m) × 3 × 2

9) Front weight 147.4kg × 4 × 2 under water

10) Buoyancy 208B × 50, Canvas kite area 17.94 m^2

11) Grand chain WA = 28 × 40 m

Figure 7. Rope trawl configuration used aboard the *Kaiyo maru* during the 2002 BASIS survey.

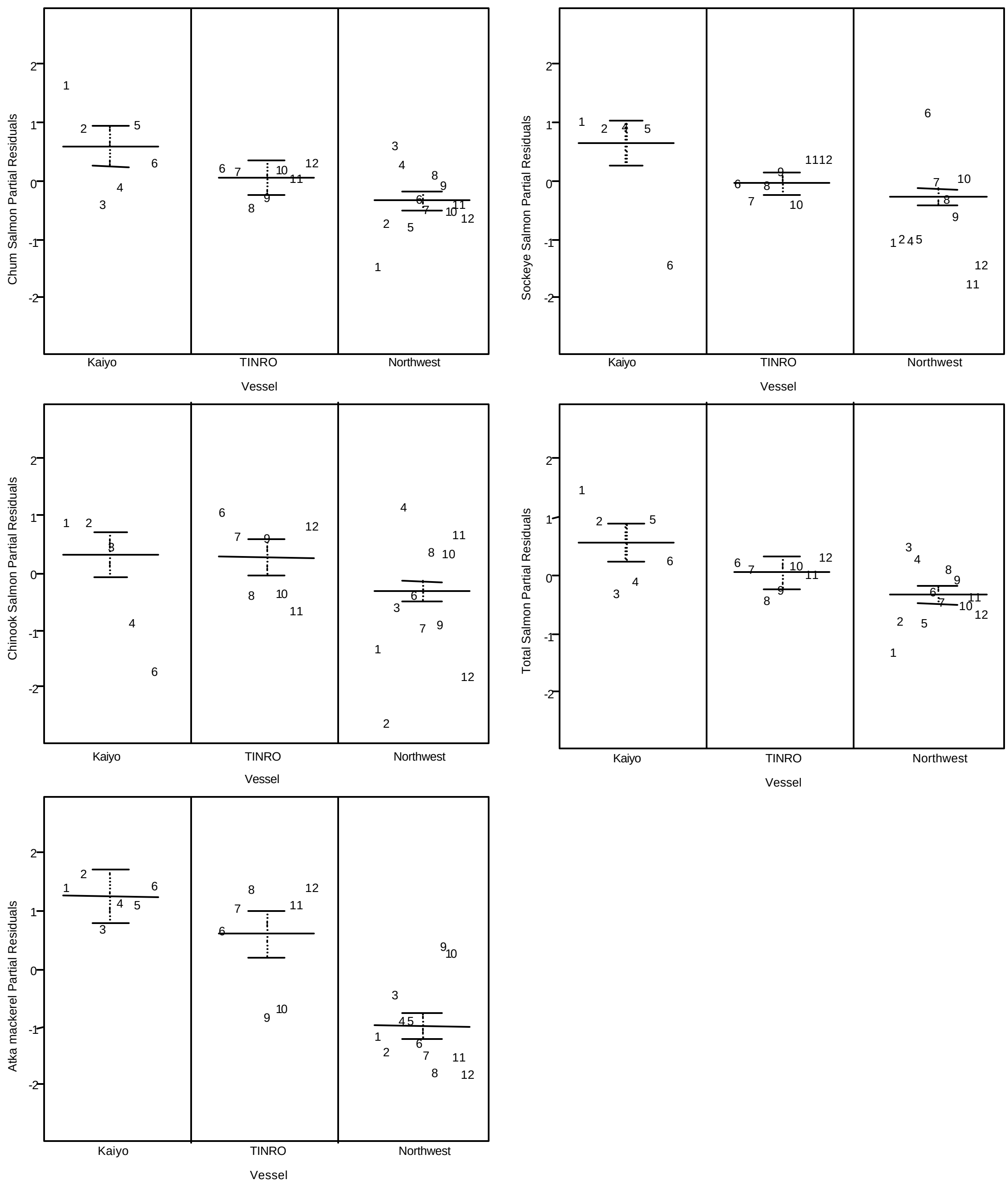


Figure 8. Partial residuals for fishing power coefficients, a_i, using CPUE of BASIS research vessels during trawl comparisons in the central Bering Sea—September, 2002. Partial residuals are identified by their consecutive station number (1-12), and fitted coefficients (wide lines) are shown bounded by ± their standard errors (narrow lines).

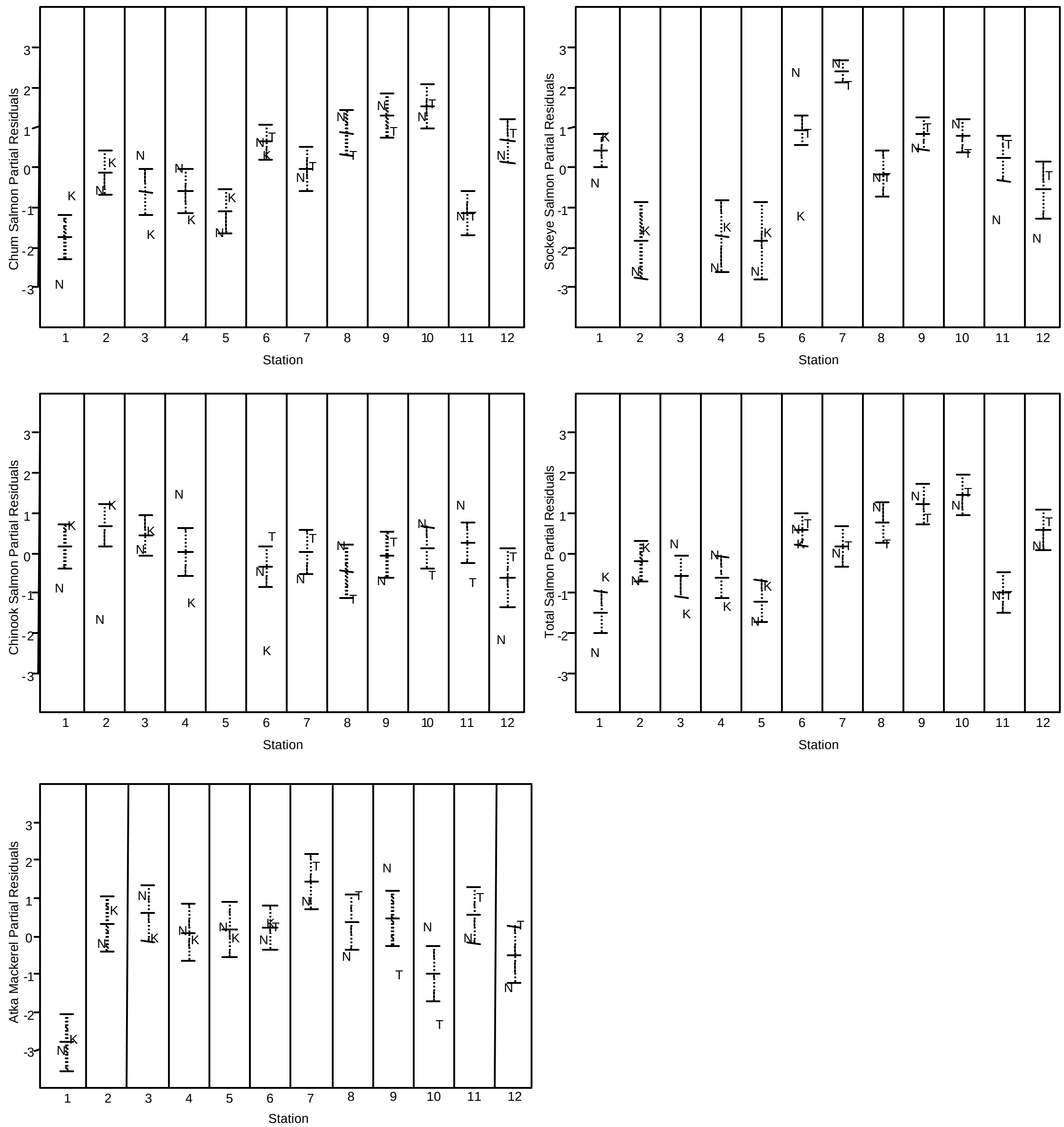


Figure 9. Partial residuals for station coefficients, b_j, using CPUE during trawl comparisons in the central Bering Sea—September, 2002. Partial residuals are identified by the respective BASIS vessel (*Kaiyo maru* = K, *Northwest Explorer* = N, *TINRO* = T), and fitted coefficients (wide lines) are shown bounded by ± their standard errors (narrow lines).

Table 1. Rope elements of the midwater rope trawl model PT 80/396 used aboard the *TINRO* during the 2002 BASIS survey.

Level	D (mm)	Length (mm)	Quantity Up-Down	Left-Right	Level	D (mm)	Length (m)	Quantity Up-Down	Left-Right
1	19	9.0	4	4	8	10	7.0	11	9
2	13	9.0	8	8	9	8	7.0	20	16
3	13	9.0	10	10	10	8	6.0	18	16
4	11	9.0	20	20	11	8	6.0	18	16
5	10	9.0	24	20	12	8	6.0	18	16
6	11	8.0	12	10	13	8	3.0	16	16
7	10	8.0	22	18	13	8	3.0	30	30

Table 2. Net elements of the midwater rope trawl model PT 80/396 used aboard the *TINRO* during the 2002 BASIS survey.

Level	Mesh (mm)	Diameter (mm)	Height (m)	Bottom basis (m) Up-Down	Left-Right	Top basis (m) Up-Down	Left-Right
1	1200	6.0	7.2	55.2	48.0	31.2	24.0
2	800	5.0	7.2	40.0	35.2	24.0	19.2
3	400	3.1	4.8	27.2	24.0	19.2	16.0
4	200	3.1	4.0	20.0	18.4	15.0	14.4
5	100	2.4	8.4	18.4	16.0	14.4	12.0
6	80	2.4	5.6	12.8	11.2	9.6	8.0
7	60	2.4	6.72	8.4	6.48	6.0	4.0
8	30	3.1	4.32	4.68	3.72	4.1	3.12

Table 3. Station and trawl information of BASIS research vessels during trawl comparisons in the central Bering Sea—September, 2002.

Vessel	Station Number	Station Name	Date (local)	Local time[1] of actual trawl period (UTC)	Position starting trawl	Position ending trawl	Average trawl speed (knots)	Distance trawled from position (m)	Distance trawled from speed (m)	Warp length (m)	Trawl opening (D×W) (m)	Area swept (km^2)	Course (degree)	Note
Kaiyo maru	1	J-27	12-Sep-02	16:06-17:06 (4:06-5:06)	514326N, 1794656W	514876N, 1794656W	5.6	10193	10371	250	50×50[3]	0.51	0	Strong tidal current.
NW Explorer	1	US-A13	12-Sep-02	16:08-17:08 (4:08-5:08)	514120N, 1794310W	514610N, 1794310W	4.8	9081	8890	360	11×45	0.41	0	
Kaiyo maru	2	J-13	13-Sep-02	8:40-9:40 (20:40-21:40)	523144N, 1773533E	523333N, 1774387E	5.7	10243	10556	250	50×50[3]	0.51	70	
NW Explorer	2	US-A14	13-Sep-02	8:35-9:35 (20:35-21:35)	523127N, 1772815E	523450N, 1773300E	4.3	8106	7964	333	16×47	0.38	70	
Kaiyo maru	3	J-12	13-Sep-02	16:09-17:09 (4:09-5:09)	530002N, 1773247E	525995N, 1774106E	5.8	9581	10742	250	50×50[3]	0.48	88	
NW Explorer	3	US-A15	13-Sep-02	16:10-17:10 (4:10-5:10)	530105N, 1773006E	530140N, 1773640E	3.8	7097	7038	387	14×45	0.32	85	
Kaiyo maru	4	J-11	14-Sep-02	8:39-9:39 (20:39-21:39)	540156N, 1773322E	540477N, 1773981E	5.6	9316	10371	250	50×50[3]	0.47	50	
NW Explorer	4	US-A16	14-Sep-02	8:30-9:30 (20:30-21:30)	540180N, 1772820E	540450N, 1773380E	4	7884	7408	504	14×45	0.36	46	
Kaiyo maru	5	J-10	14-Sep-02	16:07-17:07 (4:07-5:07)	545615N, 1772525E	545892N, 1773384E	5.7	10483	10556	250	50×50[3]	0.52	60	
NW Explorer	5	US-A17	14-Sep-02	16:00-17:00 (4:00-5:00)	545550N, 1771800E	545770N, 1772480E	4.2	8308	7778	390	14×47	0.39	60	
Kaiyo maru	6	J-4	15-Sep-02	16:08-17:08 (4:08-5:08)	545712N, 1750407E	545223N, 1750952E	7.6	10763	14075	250	50×50[3]	0.54	150	
NW Explorer	6	US-A18	15-Sep-02	16:00-17:00 (4:00-5:00)	550010N, 1750260E	550320N, 1745830E	3.6	7340	6667	315	22×40	0.29	330	Seas 15 ft. Northwest Explorer set upwind due to sea state.
TINRO	6	C1	15-Sep-02	16:36-17:36 (4:36-5:36)	545410N, 1750440W		5		9260	270	36×33.5	0.31	150	

1. Local time: UTC-12
2. *NW Explorer* and *Kaiyo maru* distances calculated from start and end positions of trawl, *TINRO* distances calculated from average speed.
3. Estimated size. Actual net opening not measured due to inoperative net sonar.

Table 3 (continued). Station and trawl information.

Vessel	Station Number	Station Name	Date (local)	Local time[1] of actual trawl period (UTC)	Position starting trawl	Position ending trawl	Average trawl speed (knots)	Distance from position (m)	Distance from speed (m)	Warp length (m)	Net opening (D×W) (m)	Area swept (km^2)	Course (degree)	Note
NW Explorer	7	US-A19	16-Sep-02	8:25-9:25 (20:25-21:25)	550009N, 1722978E	550070N, 1723663E	3.9	7367	7223	432	18×45	0.33	80	
TINRO	7	C2	16-Sep-02	8:15-9:15 (20:15-21:15)	545830N, 1723470E		4.5		8334	270	36×33.5	0.28	94	
NW Explorer	8	US-A20	16-Sep-02	16:42-17:42 (4:42-5:42)	540039N, 1723050E	540000N, 1723770E	4	7876	7408	432	18×47	0.37	95	
TINRO	8	C3	16-Sep-02	16:33-17:33 (4:33-5:33)	535940N, 1723220E		4.7		8704	292	36×33.5	0.39	95	
NW Explorer	9	US-A21a	17-Sep-02	5:20 -6:20 (17:20-18:20)	533079N, 1723003E	533010N, 1723710E	4.2	7897	7778	324	22×43	0.34	100	1st Diel
TINRO	9	C4a	17-Sep-02	5:10-6:10 (17:10-18:10)	532970N, 1723130E		4.9		9075	274	38×33	0.30	100	
NW Explorer	10	US-A21b	17-Sep-02	11:10-12:10 (23:10-24:10)	533022N, 1723036E	533030N, 1723740E	4.1	7761	7593	414	20×47	0.37	90	2nd Diel
TINRO	10	C4b	17-Sep-02	11:15-12:15 (23:15-24:15)	532930N, 1723410E		4.7		8704	300	38×33	0.29	80	
NW Explorer	11	US-A21c	17-Sep-02	17:45-18:45 (5:45-6:45)	532927N, 1723150E	532951N, 1723844E	4.3	8105	7964	360	18×47	0.38	100	3rd Diel
TINRO	11	C4c	17-Sep-02	17:37-18:37 (5:37-6:37)	532820N, 1723300E		5		9260	261	34×33	0.31	100	
NW Explorer	12	US-A21d	17-Sep-02	23:12-0:12 (11:12-12:12)	533095N, 1722840E	532760N, 1723290E	4.1	7948	7593	360	13×43	0.34	140	4th Diel
TINRO	12	C4d	17-Sep-02	23:15-0:15 (11:15:12:15)	532820N, 1723100E		4.7		8704	290	34×33	0.29	160	

1. Local time: UTC-12
2. *NW Explorer* and *Kaiyo maru* distances calculated from start and end positions of trawl, *TINRO* distances calculated from average speed.

Table 4. Catch and catch rates (CPUE) of immature salmon and juvenile Atka mackerel of BASIS research vessels during trawl comparisons in the central Bering Sea—September, 2002. Standard unit of effort is the average area swept by all vessels (0.37 km^2).

Ship	Station Number	Date	Catch					CPUE				
			Chum Salmon	Sockeye Salmon	Chinook Salmon	Total Salmon	Atka Mackerel	Chum Salmon	Sockeye Salmon	Chinook Salmon	Total Salmon	Atka Mackerel
Kaiyo maru	1	12-Sep-02	75	7	7	89	826	54.45	5.08	5.08	64.61	599.67
NW Explorer	1	12-Sep-02	3	1	1	5	58	2.72	0.91	0.91	4.53	52.52
Kaiyo maru	2	13-Sep-02	167	1	11	179	20,134	120.64	0.72	7.95	129.31	14,545.06
NW Explorer	2	13-Sep-02	26	0	0	26	800	25.25	0.00	0.00	25.25	776.95
Kaiyo maru	3	13-Sep-02	28	0	7	35	9,820	21.63	0.00	5.41	27.03	7,584.22
NW Explorer	3	13-Sep-02	49	0	2	51	2,200	56.77	0.00	2.32	59.08	2,548.65
Kaiyo maru	4	14-Sep-02	38	1	2	41	9,083	30.18	0.79	1.59	32.57	7,214.79
NW Explorer	4	14-Sep-02	41	0	4	45	1,000	42.76	0.00	4.17	46.93	1,042.91
Kaiyo maru	5	14-Sep-02	73	1	0	74	10,752	51.53	0.71	0.00	52.24	7,589.70
NW Explorer	5	14-Sep-02	10	0	0	10	1,193	9.48	0.00	0.00	9.48	1,130.48
Kaiyo maru	6	15-Sep-02	204	1	0	205	15,474	140.26	0.69	0.00	140.95	10,639.24
NW Explorer	6	15-Sep-02	62	5	1	68	650	78.14	6.30	1.26	85.70	819.19
TINRO	6	15-Sep-02	109	3	3	115	4,301	130.01	3.58	3.58	137.17	5,129.98
NW Explorer	7	16-Sep-02	31	11	1	43	1,933	34.60	12.28	1.12	47.99	2,157.26
TINRO	7	16-Sep-02	49	10	3	62	18,138	64.94	13.25	3.98	82.17	24,037.69

Table 4 (continued). Catch and catch rates (CPUE) of immature salmon and juvenile Atka mackerel.

Ship	Station Number	Date	Catch					CPUE				
			Chum Salmon	Sockeye Salmon	Chinook Salmon	Total Salmon	Atka Mackerel	Chum Salmon	Sockeye Salmon	Chinook Salmon	Total Salmon	Atka mackerel
NW Explorer	8	16-Sep-02	143	1	2	146	570	142.94	1.00	2.00	145.94	569.76
TINRO	8	16-Sep-02	67	1	1	69	9,184	85.01	1.27	1.27	87.55	11,653.33
NW Explorer	9	17-Sep-02	169	2	1	172	4,703	184.16	2.18	1.09	187.42	5,124.76
TINRO	9	17-Sep-02	123	3	3	129	1,301	151.97	3.71	3.71	159.38	1,607.42
NW Explorer	10	17-Sep-02	145	3	3	151	1,122	147.08	3.04	3.04	153.16	1,138.07
TINRO	10	17-Sep-02	228	2	2	232	356	293.69	2.58	2.58	298.84	458.56
NW Explorer	11	17-Sep-02	14	0	4	18	908	13.60	0.00	3.88	17.48	881.89
TINRO	11	17-Sep-02	17	2	2	21	8,958	20.58	2.42	2.42	25.43	10,846.46
NW Explorer	12	18-Sep-02	54	0	0	54	231	58.46	0.00	0.00	58.46	250.10
TINRO	12	18-Sep-02	113	1	2	116	4,221	145.56	1.29	2.58	149.42	5,437.06

Table 5. Average catch of salmon and Atka mackerel by BASIS research vessels during trawl comparisons in the Bering Sea—September, 2002. All vessels trawled for one hour at each station. Data for the *Northwest Explorer* is separated by the stations sampled with the *Kaiyo maru* and the stations sampled with the *TINRO*.

Vessel	Chum Salmon	Sockeye Salmon	Chinook Salmon	Total Salmon	Atka Mackerel
NW Explorer (*Kaiyo maru*)	32	1	1	34	984
Kaiyo maru	98	2	5	104	11,015
NW Explorer (*TINRO*)	88	3	2	93	1,445
TINRO	101	3	2	106	6,637

Table 6. Average catch-per-unit-effort (CPUE) of salmon and Atka mackerel by BASIS research vessels during trawl comparisons in the Bering Sea—September, 2002. Standard unit of effort is the average area swept by all vessels (0.37 km^2). Data for the *Northwest Explorer* is separated by the stations sampled with the *Kaiyo maru* and the stations sampled with the *TINRO.*

Vessel	Chum Salmon	Sockeye Salmon	Chinook Salmon	Total Salmon	Atka Mackerel
NW Explorer (*Kaiyo maru*)	35.85	1.20	1.44	38.49	1,061.78
Kaiyo maru	69.78	1.33	3.34	74.45	8,028.78
NW Explorer (*TINRO*)	94.14	3.54	1.77	99.45	1,563.00
TINRO	127.39	4.01	2.87	134.28	8,452.93

Table 7. Fishing power correction terms ($\hat{a}_i$) for catch by BASIS research vessels during trawl comparisons in the central Bering Sea—September, 2002. All vessels trawled for one hour at each station.

Reference Vessel	Species	Fishing Power Corrections		
		NW Explorer (se)	*Kaiyo maru* (se)	*TINRO* (se)
NW Explorer	Chum Salmon	-	3.42 (1.40)	1.23 (0.47)
	Sockeye Salmon	-	3.19 (1.43)	1.10 (0.28)
	Chinook Salmon	-	2.66 (1.30)	1.52 (0.73)
	Total Salmon	-	3.32 (1.26)	1.22 (0.43)
	Atka Mackerel	-	11.82 (6.61)	3.82 (1.99)
Kaiyo maru	Chum Salmon	0.29 (0.12)	-	0.36 (0.19)
	Sockeye Salmon	0.31 (0.14)	-	0.34 (0.16)
	Chinook Salmon	0.38 (0.18)	-	0.57 (0.38)
	Total Salmon	0.30 (0.11)	-	0.37 (0.18)
	Atka Mackerel	0.08 (0.05)	-	0.32 (0.23)
TINRO	Chum Salmon	0.81 (0.31)	2.77 (1.47)	-
	Sockeye Salmon	0.91 (0.23)	2.91 (1.39)	-
	Chinook Salmon	0.66 (0.32)	1.75 (1.15)	-
	Total Salmon	0.82 (0.29)	2.72 (1.34)	-
	Atka Mackerel	0.26 (0.14)	3.09 (2.24)	-

Table 8. Fishing power correction terms ($\hat{a}_i$) for CPUE based on area swept by BASIS research vessels during trawl comparisons in the central Bering Sea—September, 2002. Catches were scaled to a standard unit of effort of 0.37 km^2 of seawater, the average area swept by all vessels.

Reference Vessel	Species	Fishing Power Corrections		
		NW Explorer (se)	*Kaiyo maru* (se)	*TINRO* (se)
NW Explorer	Chum Salmon	-	2.44 (1.03)	1.47 (0.58)
	Sockeye Salmon	-	2.45 (1.17)	1.26 (0.30)
	Chinook Salmon	-	1.86 (0.87)	1.77 (0.75)
	Total Salmon	-	2.36 (0.92)	1.45 (0.52)
	Atka Mackerel	-	8.43 (4.72)	4.55 (2.37)
Kaiyo maru	Chum Salmon	0.41 (0.17)	-	0.60 (0.33)
	Sockeye Salmon	0.41 (0.20)	-	0.51 (0.26)
	Chinook Salmon	0.54 (0.25)	-	0.95 (0.58)
	Total Salmon	0.42 (0.16)	-	0.61 (0.31)
	Atka Mackerel	0.12 (0.07)	-	0.54 (0.39)
TINRO	Chum Salmon	0.68 (0.27)	1.66 (0.91)	-
	Sockeye Salmon	0.80 (0.19)	1.95 (0.97)	-
	Chinook Salmon	0.56 (0.24)	1.05 (0.63)	-
	Total Salmon	0.69 (0.25)	1.63 (0.83)	-
	Atka Mackerel	0.22 (0.11)	1.85 (1.35)	-

Table 9. Fisher's significance test for fishing power correction terms for BASIS research vessels during trawl comparisons in the central Bering Sea—September, 2002.

Species	P-value	
	Catch	CPUE
Chum Salmon	0.084	0.070
Sockeye Salmon	0.134	0.011
Chinook Salmon	0.024	0.091
Total Salmon	0.070	0.056
Atka Mackerel	0.002	0.003

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